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INTRODUCTION

The U.S. Environmental Protection Agency's research program in global climate change is designed to support the legally mandated regulatory and policy development role of the Agency; to supplement the research in global change being conducted by other U.S. agencies, other governments, international organizations, and non-government institutions. EPA has chosen to conduct research in areas where it has prior experience and expertise, and try to avoid duplication with research being conducted by other agencies of the U.S. Federal Government. Coordination of global change research among U.S. federal agencies is currently the responsibility of the Committee on Earth Sciences, which is part of the White House's Office of Science and Technology Policy.

Under this umbrella, EPA's role has been defined to be one that looks at the environmental causes and consequences of climate change. EPA specifically conducts research to assess, evaluate, and predict the ecological, environmental, and human health consequences of global change, including the interaction of plant and animal communities with the climate system. Within this broad charge, the EPA global change research program has the goals of assessing:

1) Future changes in the composition of the troposphere,

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ATMOSPHERIC SCIENCES RESEARCH IN THE US EPA CLIMATE PROGRAM

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ABSTRACT

The Office of Research and Development in the U.S. Environmental Protection Agency has begun a new research program in Global Climate Change. This program is designed to assess, evaluate, and predict the ecological, environmental, and human health consequences of global change, including the interaction of plant and animal communities with the climate system. Additional supporting areas of research in the program include: assessment and research to develop techniques to mitigate and adapt to climate change; development of emission factors and chemical models to understand and describe the production, transport, and fate of radiatively important trace gases; and evaluation of the relationship between global climate change and changes in regional climate and air quality. This paper reviews the research agenda, with emphasis on the atmospheric chemistry and climatological aspects of the program.

[1]On assignment from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

2) Biospheric response
3) Mitigation and adaptation options.

Evaluation of changes in the composition of the troposphere includes both the anthropogenically-created additions to tropospheric composition, and feedbacks caused by changes in climate. The EPA program in this area includes: (a) Characterization of sources and sinks of emissions of radiatively important trace gases and their precursors: This would include both natural and manmade sources. (b) Development of emissions models which take into account population growth, economic changes, and feedbacks. (c) Prediction of changes in the composition of the troposphere due to anthropogenic and natural emissions. Attention will be paid to both radiatively and photochemically important trace gases, their chemistry, and their impact on urban and regional air quality. (d) Development of feedback relationships between climate and emissions. (e) Evaluation of policy options regarding ways to reduce the changes in tropospheric composition.

Assessment of biospheric response includes evaluating the extent and magnitude of local to regional scale environmental changes, as a function of changes in regional climate. This includes activities involving: (a) Description of the geographic distribution of environmental resources on various scales. (b) Development of process driven response functions for small and large

areas. (c) Development of regional scenarios of changed climate which are designed for use in environmental effects studies. (d) Evaluation of environmental response to regional climate change. (e) Evaluate adaptation strategies which can be used to minimize any adverse impact on the environment.

The development of techniques for mitigating the release of radiatively important trace gases, and adapting to climate change includes: (a) The characterization and evaluation of existing mitigation techniques. (b) The development of new techniques. (c)The evaluation of policy options associated with mitigation strategies.

These objectives require a mix of scientific disciplines - but research is being done at, and in conjunction with, EPA Laboratories which are oriented along more traditional scientific lines; thus requiring an unusually high level of coordination in a scientific program.

The Laboratories involved in this program and their areas of interest are: The Air and Energy Engineering Research Laboratory, - anthropogenic emissions, mitigation and control options, and techniques development; The Atmospheric Research and Exposure Assessment Laboratory, - atmospheric sciences, tropospheric chemistry, climatology; and the Environmental Research Laboratories in Corvallis OR, Athens GA,

Duluth MN, and Newport RI, - terrestrial ecology, hydrology, biogenic emissions, and aquatic ecology.

ATMOSPHERIC SCIENCES

The research program in atmospheric sciences at the Atmospheric Research and Exposure Assessment Laboratory (AREAL), addresses the first two goals of the EPA program; to determine changes in the chemical composition of the troposphere, and to evaluate the impact of climate change on the biosphere. To do this, a number of major accomplishments are needed. They include the need to enhance the understanding of atmospheric phenomena influencing climate. This can best be explored by producing, using, and evaluating process models describing the important physical and chemical processes, and their interactions.

Based upon an understanding of the processes that control climate, and the climate record, the program will also produce regional climate scenarios that address biological and ecological response functions. Proper scenarios will incorporate appropriate meteorological and chemical dynamics which are related to the expected biological effects.

To allow for the evaluation of chemical and climate feedback processes, as well as the evaluation of the impact of climate change on air quality, regional climate scenarios

specifically designed to allow for assessment of future tropospheric and boundary layer air quality will also be produced. Variables of special interest to air quality studies, such as wind direction and speed, mixing height, and solar radiation, will be produced in these scenarios. Finally, to allow for the evaluation of model predictions, the testing of hypotheses, and the identification of important current trends, the program will conduct research to examine and identify secular climate and air quality trends on a regional and global basis. Because climate trends are difficult to detect, new statistical methods will be developed and used in this research.

These objectives serve to define the atmospheric sciences research program. To meet them, specific short and long-range research projects have been started in the fields of atmospheric chemistry and physics, climatology, and statistics.

Atmospheric Chemistry

The concentrations of many atmospheric trace species important to atmospheric chemistry and the greenhouse effect, such as CO, CO_2, CH_4, N_2O, and O_3, have been increasing. The mean rate of increase of CO_2 over the past 30 years has been about 1 ppm/yr, with indications that this rate of increase has itself increased in the past few years (Keeling, 1989). Methane, ozone, and carbon

monoxide have been increasing at a rate of about 1% per year (Blake and Rowland, 1988), (Tiao et al., 1986), (Khalil and Rasmussen, 1988). N_2O has been increasing at a rate of about .25% per year (WMO, 1985). Understanding of the trends in these gases is necessary if we are to predict both future climate change and changes in future chemical composition of the atmosphere.

This goal cannot be met until we understand the emissions of these gases from natural and man made sources, their chemical transformations in the atmosphere, their feedbacks to the biospheric system and the changes in those feedbacks as a function of changing climate. Species such as non-methane hydrocarbons (NMHCs) play an important role in tropospheric gas phase reactions involving OH radicals, NO_x, and O_3. Very little is known about the sources, chemical transformations, or biospheric feedbacks of NMHCs which would allow predictions of their future levels in the troposphere, (Pinto and Altshuller, 1989). Future levels of NMHCs and tropospheric O_3 will also impact the background levels of urban oxidants and photochemical pollution.

While not usually considered photochemical precursors, in the free troposphere the photochemical oxidation of CH_4 and CO can result in ozone formation. There is a potential for strong, non-linear coupling between these gases and OH which is not yet well understood. OH is also a sink for many halogenated hydrocarbons, such as CH_3CCl_3

and CH_3Br, which may be transported into the stratosphere and impact ozone levels there (Yung et al. 1975). It is not clear at this time how OH levels may be changing, (Pinto and Altshuller, op.cit.).

Research in atmospheric chemistry into the problems outlined above will be based upon measurements in the laboratory and field; and upon theoretical and modeling studies.

Research will be directed toward the evaluation of the effects of human activities on the global atmosphere by studying hydrocarbon and NO_x emissions, and their interaction with tropospheric ozone, and the scaling changes involved with urban to regional to global transformations and distributions of NO_x and NMHCs. Specific projects include 2-D and 3-D global chemical modeling studies: currently NO_y species are being examined, but soon the program will expand to others; and non-methane oxidation pathways, specifically looking at CO and CO_2 end products. Because measurements of trace species in the free troposphere are both so difficult and so important, remote-sensing optical instruments are also being developed and evaluated to monitor path-averaged values of O_3, NO_2, NO_3, SO_2, and other gases. A method to make gaseous flux measurements remotely, using optical techniques, is also under development.

Besides large-scale changes in the global atmosphere, it is also advisable and necessary to assess the future changes in

tropospheric composition of radiatively (CO_2, CH_4, O_3,) and photochemically (CO, CH_4, O_3) active trace species; and the anthropogenic and natural contributions to greenhouse gases. One project that we have recently started in this area looks at the ^{13}C to ^{12}C ratio along with the concentration of CO_2 to help determine if some of the anomalies observed in the increases in CO_2 could come from changes in ocean - atmosphere - biosphere exchange processes. We will also use global 2-D modeling of the distribution and isotopic contents of CO_2, CO, CH_4, to determine relative source contributions for these gases. Finally, a project to look at anaerobic oxidation of CH_4 in near coastal marine sediments will help to quantify that source/sink term.

Global atmospheric chemistry changes will be related to urban and regional air quality (O_3, visibility, and acid deposition) to determine the impact of these changes on the attainment of air quality standards. A research project to evaluate the sensitivity of urban O_3 to climate-induced changes in UV-B levels, temperature, H_2O, CO, and biogenic HCs has begun using simplified photochemical models at first; but it is expected that the more sophisticated EPA Regional Oxidant Model (ROM) and Regional Acid Deposition Model (RADM) will eventually be used. Because expected climatic and chemical changes will cause the models and their components to be used in situations for which they have not been tested, an

evaluation of chemical kinetic mechanisms in light of climate changed input variables will be made, and additional chamber studies undertaken where necessary.

It's very important to understand that the three physical scales of research presented above cannot be done in isolation from each other. Because most of the chemical reactions are concentration dependant, large scale chemical models with large time steps that try to include source and sink terms are not likely to be successful. Because many of the emissions sources are in urban areas, a nesting of models, from the urban to regional to tropospheric to global will be necessary for an accurate understanding of the transport and distribution of the important trace gases.

Climatology and Atmospheric Physics

To understand the changes that might occur in the atmosphere and biosphere from global change caused by increases in greenhouse gases, it is necessary to know what the changes in the climate will be - on scales ranging from global to regional and local, and on appropriate time scales. This level of detail is not, and will not in the next decade, be available from global climate models. The climatology and atmospheric physics research program at EPA is developing methods and applying them to provide the research community with the best scientific knowledge available on the probable states of the future atmosphere.

Statistical methods, process models, and combinations of those techniques are being used to develop descriptions of future climates, called climate scenarios, that are being used for impact and policy studies.

A scenario is defined as: *A suite of possible future climates, developed by using sound scientific principles, each being internally consistent, but none having a specific probability of occurrence attached.* This general definition applies to all elements of climate for any time in the future. However, to meet the EPA mission, there is the constraint that the scenarios must be tailored to the impact or policy study being undertaken; i.e. that it must meet user needs with regard to variables being considered, location, and time and space scales of interest.

EPA's climate scenario user needs have been determined through a recently conducted survey, (Robinson and Finkelstein, 1989). The major needs identified are:

- Simple descriptive statistics for individual climatic elements.
- Climate anomaly information, especially concerning drought.
- Information about the frequency and probability of occurrence of various threshold values.
- Synoptic information, especially concerning storms.

A review of scenario development methods

(Robinson and Finkelstein, op.cit.) has indicated that they can conveniently be broken into three categories, empirical methods, process models, and linkages of these two techniques. Empirical methods use the past climatic record, whether instrumental, historical, or paleoclimatological, to make assumptions about the future. The strength of this technique is that it provides great spatial and temporal resolution, and is available for many climatic elements. Its weakness is that it cannot readily consider changed atmospheric conditions brought about by changed forcing functions; thus process changes are deduced only by inference.

Process models strive to use the laws governing atmospheric processes to understand the present conditions and estimate future ones. Their strengths are that they explicitly incorporate the fundamental laws of physics and directly include the impact of changed atmospheric composition. Their weaknesses are that they now have very coarse spatial resolution, and that few climate elements are estimated with any confidence.

Linkage techniques combine the best of the two approaches, using predictions of elements and on scales that the climate models do best, in combination with known statistical relationships with other more difficult to model climate elements and scales.

Research now underway at EPA is addressing these three areas of scenario methods development and production. Analogue or empirical scenarios of regional climate change for environmental variables of importance to biological and ecological models and air quality studies are being produced. At the same time, better analytical techniques are being investigated. Specific research in this area includes the development of precipitation scenarios for agriculture and hydrology in the U.S.'s upper mid-west based upon a very high density and high quality data set, the development of scenarios of heat stress based upon instrumental records, and a general purpose analogue scenario based upon the similarity of past regional patterns to GCM forecasts. A special study looking at the summer of '88, the hottest summer with the highest urban ozone levels in the U.S. record, is just starting. It will specifically identify the unique climatic and circulation elements which produced the high temperatures and pollution levels.

EPA intends to work with established GCM modeling groups rather that develop its own global climate models. AREAL has, however, been very active over the past 15 years in the development of mesoscale models. Modeling research will concentrate on developing modeling techniques that allow for the direct computation of regional climate scenarios. Specific projects involve the production of techniques for the

nesting of mesoscale models with GCMs; and the improvement of mesoscale models by incorporation of more realistic moisture and cloud processes. Laboratory scientists are also working with the modeling community by providing refined data sets and analyses useful for the improvement of the GCMs. For example, the impact of surface hydrology in the GCMs is being evaluated by comparison with evapo-transpiration data so that more realistic surface feedback techniques can be incorporated into the models.

Research to develop regional scenario methods that link analogue and climate model outputs has also begun. Progress in this area takes advantage of the fact that upper level (500 and 700 mb.) flows are better predicted by global circulation models than are surface climatic elements. Two projects have begun which relate upper air circulation patterns to precipitation frequency and location, surface circulation patterns important to ozone formation, and blocking high pressure areas.

Because models need to be tested, part of the research program is developing techniques to monitor changes in regional climate and air quality due to global climate change. Work in this area involves the development of new statistical techniques to evaluate spatially distributed time series of regional variables, the adaptation of new techniques in trend analysis for subtle climate signals, and the development of techniques to evaluate the

statistics of meteorological thresholds. While these three projects are useful for trend evaluation, they have also been designed to be applicable to scenario development as well.

SUMMARY

Man's influence on climate cannot be "proven"; but his influence on the chemical composition of the atmosphere, including the radiatively important trace gases, is indisputable. While the implications of greenhouse gas build-up and the proper societal reactions to that build-up should be debated, it is obviously prudent to understand as much as we can about the causes and consequences of climate and climate change. The research program presented here is one part of one U.S. federal agency's scientific program in response to the problem. It is not, and was never designed to be the whole answer. But we hope that, in combination with a world-wide commitment to advancing man's understanding of our planet, the proper course to take in protecting the Earth will become obvious.

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